

gas by utilizing (a) a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range; and (b) a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream.

The first recirculating refrigeration system may be operated by

- (1) compressing a first gaseous refrigerant;
- (2) cooling and at least partially condensing the resulting compressed refrigerant;
- (3) reducing the pressure of the resulting at least partially condensed compressed refrigerant;
- (4) vaporizing the resulting reduced-pressure refrigerant to provide refrigeration in the first temperature range and yield a vaporized refrigerant; and
- (5) recirculating the vaporized refrigerant to provide the first gaseous refrigerant of (1).

At least a portion of the cooling in (2) may be provided by indirect heat exchange with one or more additional vaporizing refrigerant streams provided by a third recirculating refrigeration circuit. The third recirculating refrigeration circuit may utilize a single component refrigerant or alternatively may utilize a mixed refrigerant comprising two or more components.

In an alternative embodiment, the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing (a) a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range; and (b) a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The second recirculating refrigeration system may be operated by

- (1) compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant in (b);
- (2) cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;

- (3) work expanding the cooled gaseous refrigerant to provide the cold refrigerant in (b);
- (4) warming the cold refrigerant to provide refrigeration in the second temperature range; and
- (5) recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

At least a portion of the cooling in (2) may be provided by indirect heat exchange with one or more additional vaporizing refrigerants provided by a third recirculating refrigeration circuit. The third recirculating refrigeration circuit may utilize a single component refrigerant or a mixed refrigerant which comprises two or more components.

In another alternative embodiment, the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing (a) a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range; and (b) a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The first refrigerant system may be operated by

- (1) compressing a first gaseous refrigerant;
- (2) cooling and partially condensing the resulting compressed refrigerant to yield a vapor refrigerant fraction and a liquid refrigerant fraction;
- (3) further cooling and reducing the pressure of the liquid refrigerant fraction, and vaporizing the resulting liquid refrigerant fraction to provide refrigeration in the first temperature range and yield a first vaporized refrigerant;
- (4) cooling and condensing the vapor refrigerant fraction, reducing the pressure of at least a portion of the resulting liquid, and vaporizing the resulting liquid refrigerant fraction to provide additional refrigeration in the first temperature range and yield a second vaporized refrigerant; and

(5) combining the first and second vaporized refrigerants to provide the first gaseous refrigerant of (1).

Vaporization of the resulting liquid in (4) may be effected at a pressure lower than the vaporization of the resulting liquid refrigerant fraction in (3), and the second vaporized refrigerant may be compressed before combining with the first vaporized refrigerant.

In a further alternative embodiment, the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing (a) a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range; and (b) a second refrigeration system which provides refrigeration in a second temperature range by work-expanding a pressurized gaseous refrigerant stream. The second recirculating refrigeration system may be operated by

- (1) compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant in (b);
- (2) cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;
- (3) work expanding the cooled gaseous refrigerant to provide the cold refrigerant in (b);
- (4) warming the cold refrigerant to provide refrigeration in the second temperature range; and
- (5) recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

The feed gas may be natural gas, the resulting liquefied natural gas stream may be flashed to lower pressure to yield a light flash vapor and a final liquid product, and the light flash vapor may be used to provide the second gaseous refrigerant in the second refrigerant circuit.--